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Improving Algorithms at D0

D0 is a physics group that is based at Fermilab. There in Batavia Illinois, there are four main types of particle physics studied: electro-weak (EW) physics, top physics, new phenomenon, and B physics. Recently an upgrade was made to the detector in order to improve the results from Run I (1992-1996) to Run II (started in March 2001). This will allow for discovery and/or confirmation of data for the physics community.

The new detector (see Figure 1) consists of an inner silicon vertex detector, surrounded by eight superlayers of scintillating fiber tracker. This detector is in a 2 Tesla superconducting solenoid. Between the outer radius of the solenoid and the inner radius of the central calorimeter cryostat is a scintillator based central preshower detector with wavelength shifter readout. This is used to aid in electron identification and to compensate for energy losses in the solenoid. The calorimeter consists of liquid argon and uranium or steel and measures the energy of the particles. [1] Just outside this is the muon detector.

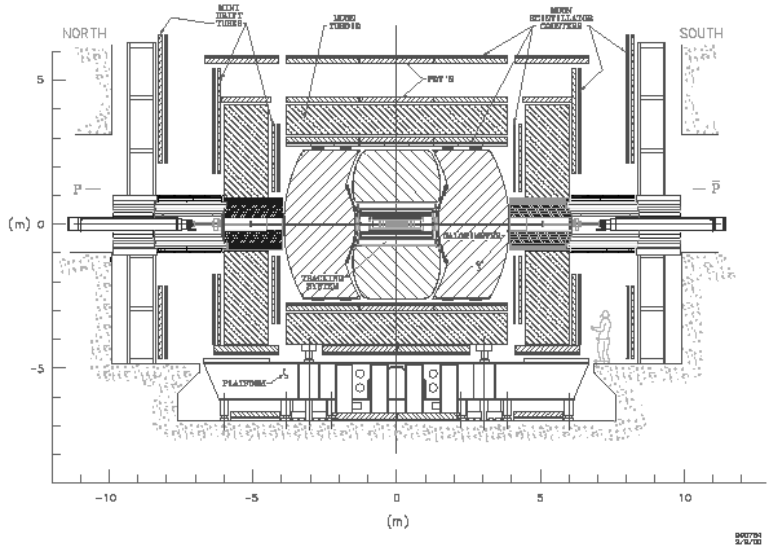

Figure 1: Side view of D0 upgrade detector. [2]

The curious reader may wonder, "Muons are just overweight electrons. Why bother to detect them?" It turns out muons are not so useful to look at by themselves. The key part of detecting muons is to look from where and what they came from. Muons happen to be the products of decays that indicate certain properties of EW physics, top physics, etc. and help achieve the goals of the D0 collaboration.

There are three layers in the muon detector system designated as A, B, and C, where A is closest to the interaction region, and the toroid magnet is located between the A and B layers (see Figure 2). This magnet is useful in determining the momentum of the particle. The mini-drift tubes (mentioned above) are arranged in three layers (A,B,C) with (4,3,3) decks of tubes per plane. In addition there are three layers (A,B,C) forward muon scintillators. As for the central muon detector, precision drift tubes and scintillators are used. [4]

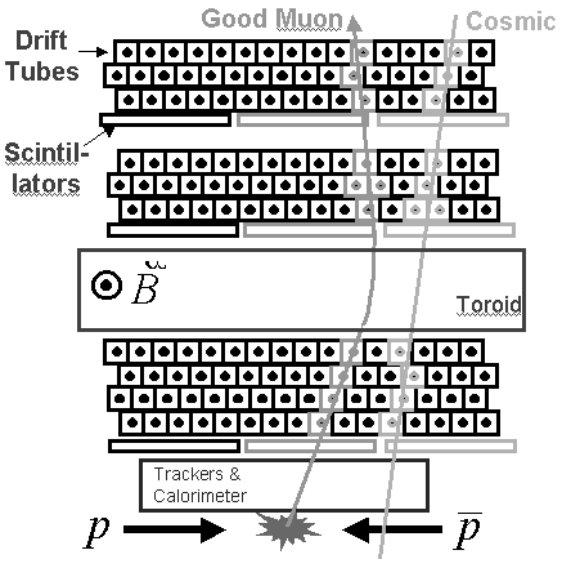

Figure 2: Tracking muons. [2]

The trigger is a device to select events as they happen so they can be written to tape. There are three major modules of the D0 trigger, in order to gradually decrease the 7 MHz input rate to a final accept rate of 20 Hz. The first trigger level (L1) includes information from scintallators, tracking, and calorimeter detectors. The second trigger level (L2) identifies higher quality physics objects and seeks for correlations between L1 triggers by incorporating processing modules assigned to specific subdetectors and a single global processor. The third detector (L3) is a computer farm that reconstructs events and identifies interesting topologies using a set of physics tools and filters. [3]

With fast electronics, L1 is able to determine muon candidates (in 2D) using tracks from LICTT and hits in the muon chambers. The second level, using only the muon system, is able to track the muons in 3D with more precisely calibrated data than was available at L1. At the heart of L3 are complex algorithms combined with track and calorimeter information to make the final cut between muons and other particles. Part of this flow can be seen in Figure 3.

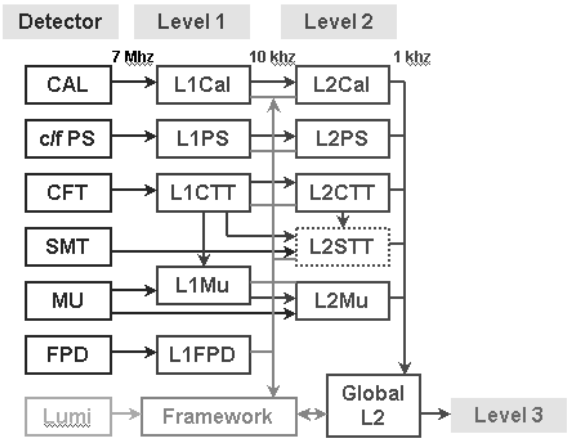

Figure 3: L1 and L2 triggers. [2]

As mentioned before, each level decreases the amount of information passed to the next element in the chain. This is done through algorithms that discriminate against and select certain particles based on their attributes. The best way to test the L2 muon algorithm is by simulation. Using a series of programs and macros, it is possible to create a virtual event, run it through the detector, and analyze the results.

Events identical to those at Fermilab are created virtually: proton anti-proton collisions (see Figure 4).

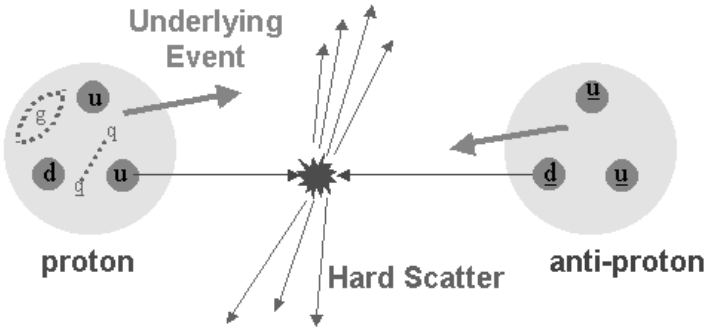

Figure 4: Bang! Snap! Crackle! [2]

Specially written Monte Carlo programs simulate the hard scattering process and the underlying event of the collision, then two programs called d0gstar and geant are used to simulate the detector and record the signals. Additional interactions are then recorded.

Next another program, D0sim, digitizes the information. At the end of this, the offline reconstruction of the tracks, trigger objects, etc. are recorded into an n-tupple so that the data can be conveniently looked at and analyzed.

The muon that are recorded can be thought of as either "Monte Carlo" or "trigger" muons. The Monte Carlo muons are the muons that are created in the simulation. The trigger muons are the muons that are detected by the trigger simulator. If the simulation programs are working perfectly, these two definitions should correspond to the same physical particle, with all its properties being identical in both. There are two reasons why this is the case. The detector does not measure the particle properties perfectly, so the detector resolution is not perfect. Secondly, there are bugs in the trigger algorithm and/or a non-optimal algorithm.

To analyze the data that was recorded, a series algorithms were used to "match" the Monte Carlo muons with trigger muons. By doing this, it was possible to see how efficiently the trigger algorithm could detect the generated muons.

The basic idea with matching is to nest one for-loop in another for-loop. One of the for-loops cycle through the Monte Carlo particles, and the other for-loop cycles through the trigger particles. By using a variable that is in common and similar between the particles in question, it is possible to accurately decide that two particles are the same.

In addition to changing the variable that is used to match the particles, one can set certain parameters that restrict the trigger muons to muons with specific attributes. For instance, as a general rule: matching algorithms should not include trigger muons if the variable "matchType" is equal to one or two. If matchType is equal to these numbers, the particle only has L1 and L1&A information, respectively. Because these were the only

stubs that it had, it could not determine transverse momentum and was thus less precise than muon candidates with info form all layers (A,B,C).

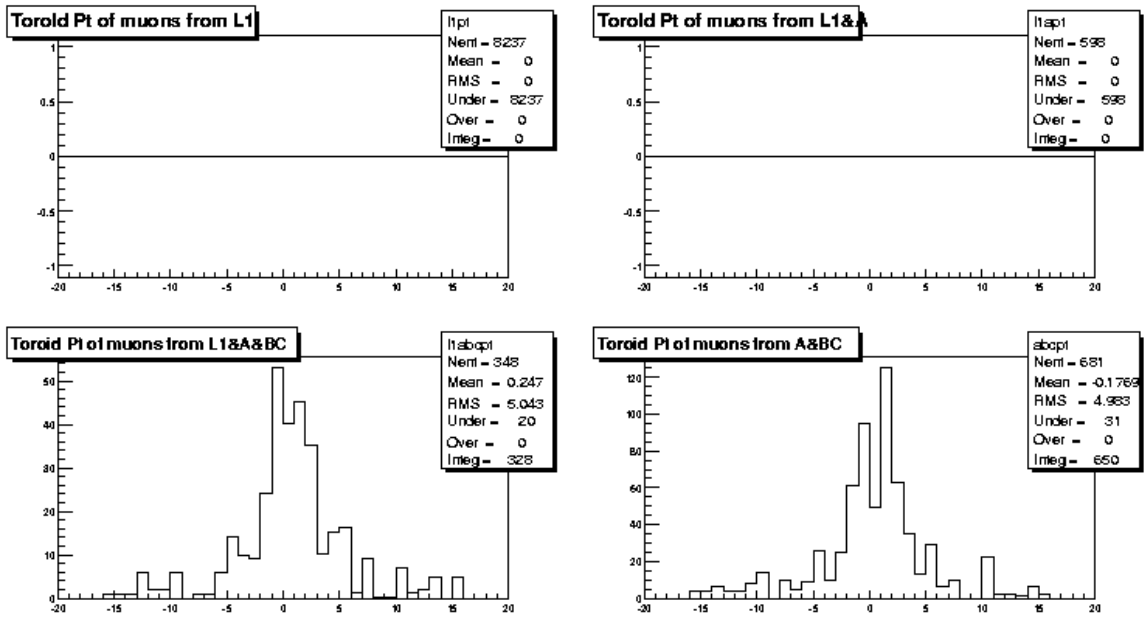

Figure 5: matchType is used to exclude data that is not needed.

Careful discrimination of variables such as this, are just as useful in matching as the variables that were chosen to match by.

In the first case of matching, transverse momentum was used to determine a match. After running through the nested loops, the two particles with the smallest difference in transverse momentum are considered to be matched or the same. Unfortunately this matching proved poor, due to a resolution of 0.25 GeV. This means that the information was too coarse to accurately distinguish between trigger muons and Monte Carlo muons.

A different matching algorithm used ΔR, where $\Delta R = \sqrt{(\Delta\eta^2 + \Delta\varphi^2)}$. Here φ is the azimuthal that measured by the detector, and $\eta = -\ln(\theta/2)$ where θ is the polar angle in the detectors cylindrical coordinates. The same matching loop was used and a minimal ΔR

was found for each particle. This worked on basically the same idea as difference in transverse momentum.

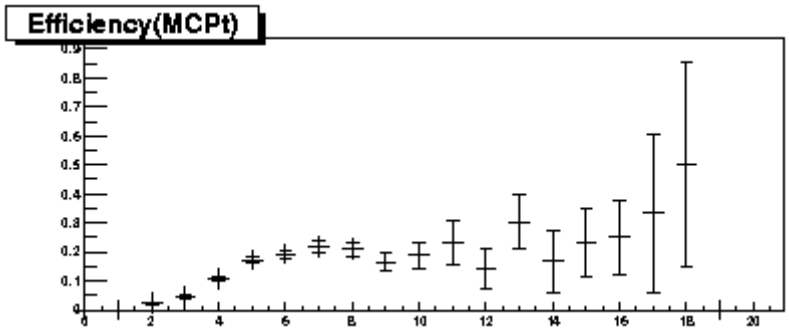

Figure 6: Efficiency of delta R matching.

But this result had a noticeable increase in efficiency due to the improvement in resolution of the variables involved.

In the final algorithm tested the efficiency by matching the Monte Carlo muons and trigger muons, then using that information to calculate a known quanity.

The idea here was based on the decay of $J/\psi \rightarrow \mu^+ + \mu^-$. The invariant mass of the two muons is equal to the invariant mass of the J/ψ particle. By looking at the muons that come from the J/ψ particle, taking the invariant mass and putting it in a histogram, there should be a peak at 3.1 GeV (invariant mass of the J/ψ particle).

In the program, the Monte Carlo and the detector muons were matched using the ΔR method. A second set of nested for-loops were implemented and plotted the invariant masses of the two muons that came closest to the invariant mass of the J/ψ.

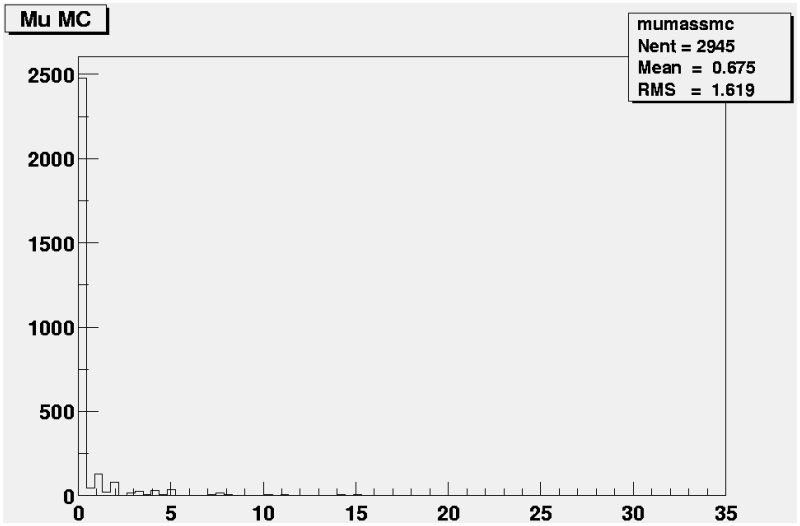

Figure 7: Peak around zero, and no peak at 3.1 GeV.

If the matching was good and the data was good there should be a peak exactly at the 3.1 GeV as with the very first graph. The fact that there is no peak seen at 3.1 GeV, says that there are major inconsistencies between the Monte Carlo and trigger muons.

"My favorite part about simulated particles is how they aren't real. What use does this have?" piped up the cynically curious reader again. A large problem is the background particles that are detected by the muon trigger. Particles mistaken for hits come from various places. For instance, some detected particles come form cosmic rays. Others are "punch though," particle that go through the detector and cause hits in the muon system. Some come from the decay products of pions and kaons produce in the p p-bar collision. The goal is to eliminate as many of these discrepancies. To do so, efficient algorithms are needed. These tests make the algorithms as efficient and bug free as possible.

This identification of problems through trial and test are the major contributions of these tests to D0. By figuring out the problems with the results, the programmers at

Fermilab can debug their code, ensuring that the virtual mistakes will not carry over to reality.

Bibliography

[1] http://higgs.physics.lsa.umich.edu/dzero/d0doc96/d0doc/p0507.ps

[2] Summer Talk to Quarknet at Nevis Labs by Hal Evans (2001)

[3] http://www.nevis.columbia.edu/~christos/tempFolder/chep01.ps

[4] http://higgs.physics.lsa.umich.edu/dzero/d0doc96/d0doc/p2635.ps